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HIGH-VOLTAGE THREE-ELECTRODE ELECTRON GUN,(U)

OCT 78 K P RYBAS, A T YERMOLAYEV

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By

K. P. Rybas and A. T. Yermolayev

FOREIGN TECHNOLOGY DIVISION

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

HIGH-VOLTAGE THREE-ELECTRODE
ELECTRON GUN

K. P. Rybas and A. T. Yermolayev

Electron guns, which can provide well-focused electron beams at high current, are necessary for the development of the high-intensity electron accelerators. In some cases the electron guns must permit one to change the magnitude of the beam current without changing the divergence angle and the energy of the beam.

In this work we have studied the effect of the cathode's position along the axis of the Pierce-type gun [1] [Translator's note: not sure if the spelling of the name is correct] on the focusing of the beam and other parameters of the gun. On the basis of these studies a three-electrode gun was developed for pulsed operation at 80 kV with a current in the beam of up to 5 A, which made it possible to vary the magnitude of the beam current without changing the angle of divergence and the power of the beam.

2. Examination of the Pierce-type electron gun

An electron gun with the Pierce's optics shown in Fig. 1 was constructed for carrying out experiments. The gun utilized an oxide-coated cathode 8 mm in diameter which could be moved relative to the anode without disrupting the vacuum. The gun was installed in a vacuum metal chamber, into which a collector was introduced for measuring the beam current and a fluorescent screen for determining the beam diameter at various distances from the gun. The displacement of the collector and the fluorescent screen was ac-

complished without disrupting the vacuum. The gun was studied in a pulsed mode (duration of a pulse - 5 μs, repetition frequency - 50 pulses/s) at a voltage of 20 and 80 kV.

Figure 2 shows images of a beam on the fluorescent screen at various positions of the cathode relative to the anode. In this case the distance between the cathode and anode electrodes was constant. $\Delta S=0$ corresponds to the calculated distance between the cathode and anode S=15 mm. The positive ΔS correspond to the increase, while the negative ΔS - to the decrease in the distance between the cathode and the anode. As seen from Fig. 2, when $\Delta S=0$, a uniformly luminous spot with clear boundaries is seen on the fluorescent screen. With negative ΔS the diameter of the spot increases with a uniform luminescence along the beam's diameter (on the right in Fig. 2). When the ΔS are positive, a halo with sharp boundaries appears around the main spot (on the left in Fig. 2). As the ΔS increases the diameter of the main spot decreases, while the diameter of the halo increases.

The appearance of the halo can be explained qualitatively in the following manner. As the cathode recedes into the cathode electrode, due to the sagging of the equipotentials towards the cathode, the radial component increases and the longitudinal component of the electrical field decreases at the edge of the cathode. As a result, there is a considerable decrease in the number of electrons extracted from the edges of the cathode; furthermore, the outer electrons have a stronger deflection towards the axis, which leads to the formation of a halo, as shown schematically in Fig. 3.

Figure 4 shows the beam current I_n, current to the anode I_a, beam divergence angle α, and the divergence angle of the beam's halo α_1 as a function of ΔS; the curves were plotted at a pulsed voltage of 20 kV.

As seen from the figure, the divergence angle of the main beam α with positive ΔS is approximately constant. With a decrease in ΔS the beam divergence angle α increases sharply reaching 1.3° when $\Delta S=-0.8$ mm. This is explained by the disruption of the focusing conditions in the Pierce's optics as the distance between the

cathode and the anode decreases relative to the optimum. It is also seen from Fig. 4 that a halo, whose divergence angle α increases sharply with an increase in ΔS, attaining 4.3° when $\Delta S = +0.5$ mm, appears when the ΔS are positive. According to the measurement data, the fraction of the beam current expended on the halo does not exceed 25% of the total beam current.

When a tungsten cathode in the form of a flat spiral was substituted for the oxide cathode in this gun, the divergence angle increased by more than 8 times. Apparently, this is explained by the distortion of the electrical field in the gun, caused by the configuration of the emitting surface of the cathode and, in accordance with this, by the unequal density of the emission current along the cross section of the beam.

3. Three-electrode electron gun

On the basis of the experiments described above, one can design a three-electrode electron gun which would allow one to vary the beam current without changing the angle of divergence and the energy of the beam.

In the three-electrode electron gun shown in Fig. 5 the electron energy is determined by the voltage U_2 applied between the cathode and a second anode. The beam current is regulated by changing the voltage U_1 applied between the cathode and the first anode. The change in the voltage U_1 also changes the lens power formed by the first and second anodes, as a result of which, the change in U_1 also changes not only the magnitude of the beam current but also the beam's angle of divergence at the output from the second anode and, as shown by the experiment, rather significantly. However, the divergence angle of the beam at the output from the second anode can be made constant by changing U_1 if, accordingly, we change the divergence angle of the beam at the outlet from the first anode. As seen from Fig. 4, this is easily accomplished by changing the position of the cathode.

It follows from Fig. 4 that, when $\Delta S = 0.8$ mm the divergence angle α of the beam at the outlet from the first anode is equal to 1°18'. In this case, the imaginary point source of the electrons will be at a distance $l = 110$ mm from the first anode (see Fig. 5,a).

In order to obtain a parallel beam at the outlet from the second anode, it is necessary that the position of the imaginary point source of electrons would coincide with the position of the first focus of the lens formed by the first and second anodes. Using the optical characteristics of the lens formed by two diaphragms with the ratio

$$\frac{A}{D} = 5$$

(Fig. 6, see also Fig. XI. 31 in work [21]), where A - distance between the first and second anodes and D - opening diameter in the anodes, in our case equalling to 5 mm, we find the focus distance of the lens formed by the first and second anodes.

Consequently, A=5D=2.25 mm.

As it follows from Fig. 6, when

$$\frac{U_2}{U_1} = 2.8 \; F_1 = 4.9A = 122.5$$

where F_1 - distance between the first focus and the plane which is in the middle between the first and second anodes.

Consequently, when $\Delta S = -0.8$ mm, the focus of the lens formed by the first and second anodes coincides with the position of the imaginary point source of electrons (see Fig. 5,b)

$$F_1 = l + \frac{A}{2}$$

As it follows from Fig. 6, the focal distance of the lens increases with an increase in the current of the electron beam due to an increase in U_1. Consequently, in order to obtain a parallel beam with an increase of current in the beam, the imaginary source of electrons must be moving away from the anode, i. e., the angle of divergence of the beam at the output from the first anode must decrease. As it follows from Fig. 4, the decrease in the beam divergence angle is achieved by displacing the cathode in the direction opposite to the anode. Thus, with another limiting value of $\frac{U_2}{U_1}$, which is close to unity, the beam emanating from the first anode with $\alpha = 0.4°$ will be focused, which occurs when $\Delta S = 0$.

As it follows from the 2/3 law, when U_1 increases by 2.8 times (U_2 is constant) the beam current will increase by 4.7 times, i. e., in this case, the value of the beam current can be changed by almost 5 times without varying the divergence angle of the beam at the outlet from the gun.

A similar calculation method was used to develop the high-voltage three-electrode electron guns of the type EP-6 and EP-9.

Figure 7 shows the general view of the electron gun, EP-9. The electron guns, EP-6 and EP-9, were designed to operate in a pulsed mode at a voltage of up to 80 kV, which permit one to regulate the beam current without changing the energy of the beam's electrons at a virtually constant divergence angle of the beam. The maximum current in the beam reaches 5 A.

In this gun, cathode 1 with the cathode electrode 2 and the first anode 3 represent the Pierce's optics and a flat diaphragm was used as the second anode 4. An electron beam is formed by means of the Pierce's optics and the magnitude of the beam's current is controlled by varying the voltage applied between the cathode and the first anode. The primary function of the section, first anode—second anode, is the acceleration of the electron beam formed by the Pierce's optics up to 80 keV. The variation in the effect of the first anode-second anode section on the focusing of the beam during the regulation of the beam current is compensated by the corresponding displacement of the cathode along the gun's axis.

Better results are obtained when the optics of the electron gun operates at the following distances between the electrodes: 32 mm between the cathode and first anode; 20 mm between the first and second anodes.

The construction of the electron gun, EP-9, is such that it can be disassembled completely. Rubber seals are used in places where the components are joined together. Cathode 1 with the cathode electrode 2, the first anode 3, and the second anode 4 are insulated from one another by means of finned insulators 7 and 8 made from steatite, which are glued to metal flanges. The cathode with a cathodic electrode is under a potential of —80 kV; depending on

the magnitude of the beam current, the potential of the first anode is regulated in the range of values from zero to −75 kV and the second anode is at the potential of the ground. For this reason the insulators 7 and 8 are calculated for a total operating voltage of 80 kV.

Windows have been provided in the electrode holders 5 and 6 for pumping out. Good focusing is achieved due to the possibility of the cathode displacement under vacuum. The displacement of the cathode stem 10 is accomplished by a helical clearance-free reducer 11 with the transmission ratio of 1:100. Motion from the motor to the reducer is transmitted by means of a shaft made from the insulation material, rated at 80 kV.

Barium-nickel cathode is used in the electron gun EP-6. The EP-9 gun uses a tantalum cathode 1 14 mm in diameter with an electron heating. A tungsten spiral 9 made from a wire 0.8 mm in diameter is used as an additional cathode for electronic heating of the main cathode 1.

Figure 8 shows the curves of an electron gun of a type EP-6 and EP-9. The ratio of the voltage U_1 applied between the cathode and first anode to the total voltage U_2 applied between the cathode and the second anode is plotted along the axis of abscissas (the value of U_2 was constant at 80 kV). The beam current I_n and the displacement of the cathode ΔS necessary in order that the beam divergence angle α at the outlet from the gun did not exceed 30' during the change in the ratio $\frac{U_1}{U_2}$ was plotted along the axis of the ordinates.

As seen from Fig. 8, the beam current can be varied in the range from 1 to 5 A by changing the ratio $\frac{U_1}{U_2}$ in the range from 0.33 to 1 with a simultaneous displacement of the cathode along the gun's axis by 1.5 mm. In this case the beam divergence angle α does not exceed 30'. When the current is varied the diameter of the beam at the outlet from the gun changes from 2 to 5 mm. If one does not impose rigid requirements on the beam divergence angle, the beam current can be varied over a wider range from 0.1 to 5 A by the indicated method. The beam current is regulated by remote control by changing the value of the voltage U_1 with a simultaneous

automatic variation of the cathode's position.

In conclusion we express our appreciation to T. N. Shlychva and B. N. Telepayev for their development of the tantalum cathode with electronic heating; Z. N. Solnyshkova, N. A. Kiselyeva, V. K. Paplov, and V. A. Veselov for their development of the barium-nickel cathode; and G. I. Borisova for her participation in certain experiments.

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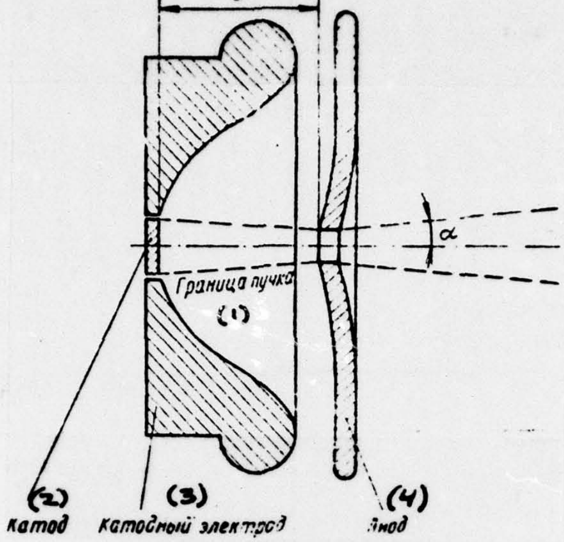

Fig. 1. Pierce's electron gun.

Key: (1) Beam boundary (2) Cathode (3) Cathodic electrode (4) Anode

Fig. 2. Images of the electron-beam cross section on a fluorescent screen at various positions of the cathode relative to the anode.

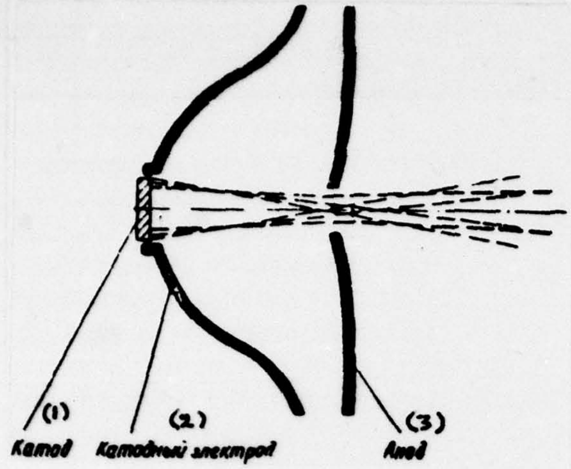

Fig. 3. Electron trajectories in the Pierce's gun for the case when the cathode is recessed in the cathodic electrode.

Key: (1) Cathode (2) Cathodic electrode (3) Anode

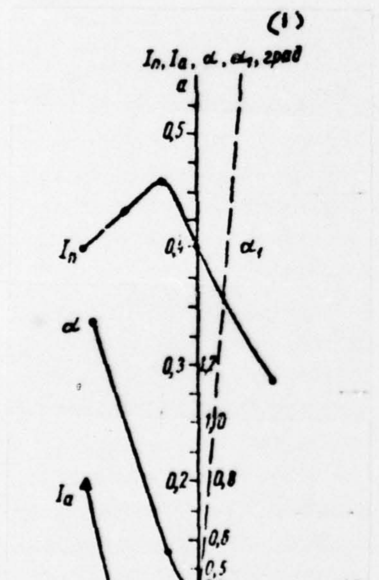

Fig. 4. Beam current I_n, current to the anode I_a, beam divergence angle α, and the divergence angle of the beam's halo α_1 as a function of the cathode's displacement relative to the anode ΔS.

Key: (1) degrees (2) to anode

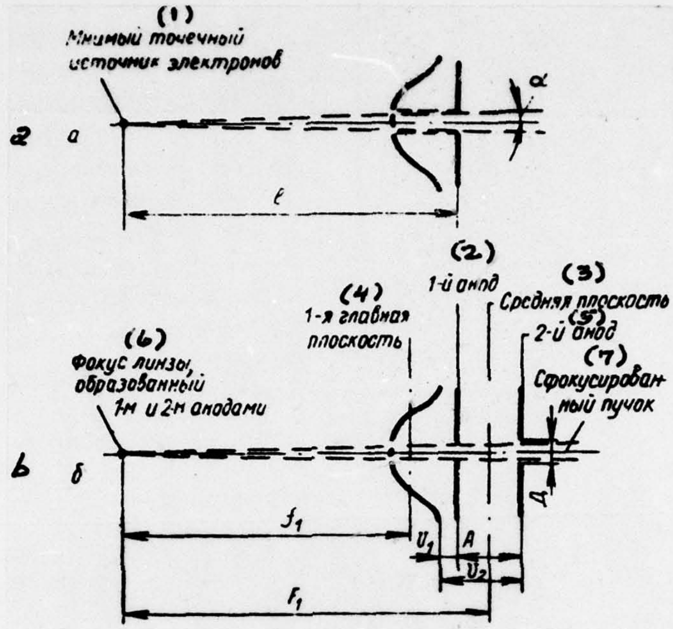

Fig. 5. Imaginary electron source in a two-electrode gun of the Pierce's type (a) and electron-optical characteristics of a three-electrode gun (b).

Key: (1) Imaginary point source of electrons (2) 1st anode (3) Middle plane (4) 1st main plane (5) 2nd anode (6) Lens focus formed by 1st and 2nd anodes (7) Focused beam

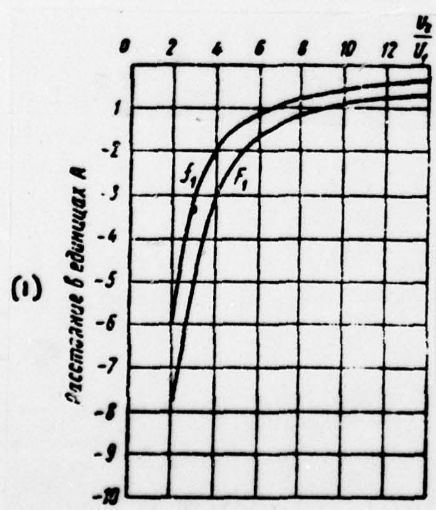

Fig. 6. Optical characteristics of a lens formed by two diaphragms with the ratio $\frac{A}{D}=5$.

Key: (1) Distance in units A

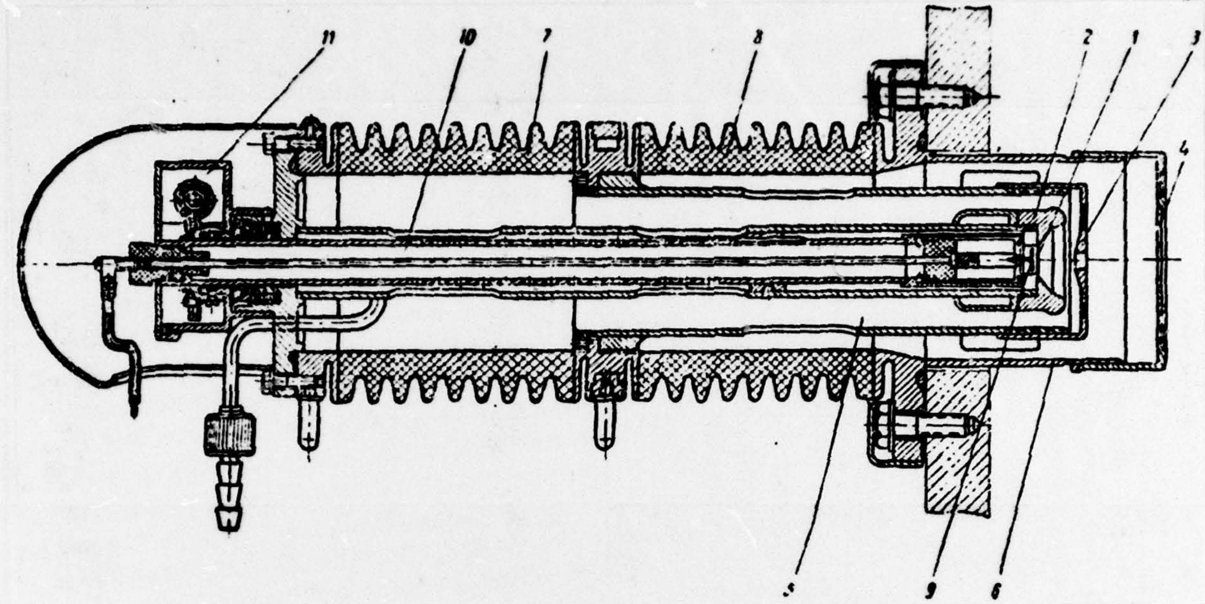

Fig. 7. Overall view of the electron gun EP-9.

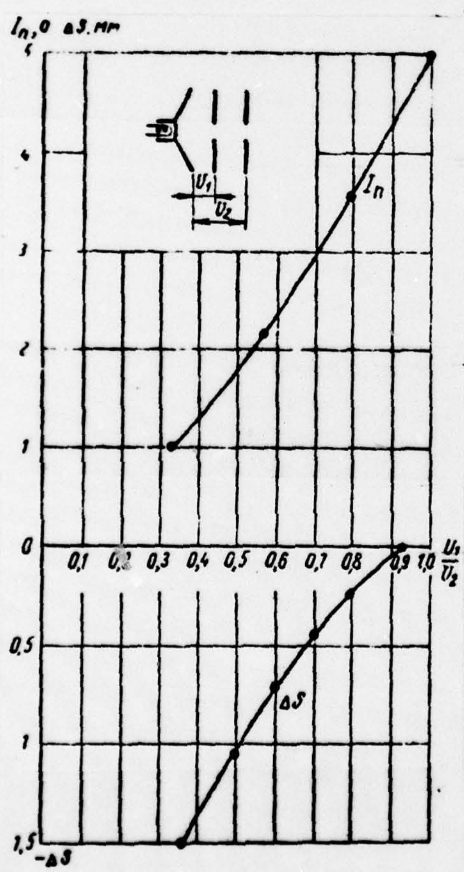

Fig. 8. Characteristics of the electron guns EP-6 and EP-9.

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